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(71) Applicant (*for all designated States except US*): **COMINET CORPORATION** [KR/KR]; Ilsok Bldg. 4th Floor, 162-2 Samsung-dong Kangnam-gu, Seoul 135-090 (KR).

(71) Applicant and
(72) Inventor: **SHIN, Seo-Yong** [KR/KR]; 10 Myungji Maeul, 33-1 San, Nam-dong, Yongin-shi 449-030 (KR).

(74) Agent: **HUH, Jin-Seok**; J.s. Huh Patent Office, 206 Sungji Bldg., 1338-22 Seocho-dong, Seocho-ku, Seoul 137-070 (KR).

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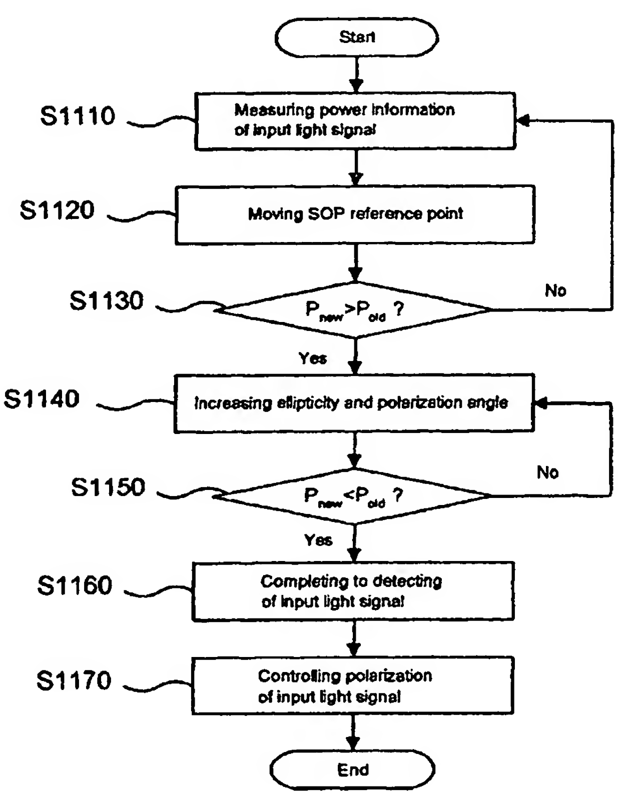

(57) Abstract: The present invention relates to an apparatus and method which provide real-time detection of randomly varying instantaneous stateof polarization (SOP) and control the SOP at a user's will on the basis of detection value. In the present invention, an algorithm is employed that makes the SOP of the reference optical signal coincide with the SOP of the input optical signal, minimizing the calculation time for polarization control. Therefore, it is possible to detect an SOP and to control the SOP in a minimum time.

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APPARATUS AND METHOD FOR REAL-TIME DETECTION AND CONTROL OF POLARIZATION STATE

TECHNICAL FIELD

The present invention relates to an apparatus and method for controlling polarization of an optical signal, and more particularly, to an apparatus and method for detecting a polarization state which is randomly varied with time in an optical signal in real time and thereby freely controlling the polarization state.

BACKGROUND ART

Generally, polarization control systems are being widely used in optical appliances such as optical fiber sensor, optical interference system, and optical communications system. As one example in the optical communications system using the optical fiber, a light irradiated from a light source, such as a semiconductor laser with a narrow frequency band, is propagated through a single mode optical fiber. Optical modulator modulates the light signal propagated through the single mode optical fiber. At this time, due to inherent birefriengence of the optical fiber or thermal and mechanical stresses applied to the optical fiber, a state of polarization (SOP) in the modulated light signal is varied with time elapsed in a receiving unit of the optical communications system. For instance, it is general that linearly polarized light signal propagated through the optical fiber is converted into elliptically polarized light as it arrives at a receiver. Accordingly, it is necessary to compensate for a change in the state of polarization.

FIG. 1 is a schematic view of a system for detecting light power depending on states of polarization in input light signal and light signal of reference light source. Referring to FIG. 1, an input light signal 100 and a reference light signal 110 of a reference light source are mixed with each other by a beam coupler 120 and are then detected by a photo-detector 130. The input light signal 100 is generally transmitted through a light waveguide such as an optical fiber from a place distant from the photodetector 130, and the reference light signal 110 is output from a laser beam source

or the like around the photodetector 130.

Detected signals are output in the form of bit stream 150 by an electronic circuit 140.

Here, electric field vectors, $\overline{E_s}$ and $\overline{E_{LO}}$ of the input light signal 100 and the reference light signal 110 are respectively expressed as the following equations 1 and 2:

Equation 1

$$\overline{E_s} = \overline{A_s} \exp[-i(\omega_0 t + \phi_s)]$$

Equation 2

$$\overline{E_{LO}} = \overline{A_{LO}} \exp[-i(\omega_{LO} t + \phi_{LO})]$$

where, ω_0 is the frequency of the input light signal 100, $\overline{A_s}$ is the amplitude of the input light signal 100, $\overline{\phi_s}$ is the phase of the input light signal 100, ω_{LO} is the frequency of the reference light signal 110, $\overline{A_{LO}}$ is the amplitude of the reference light signal 110, and $\overline{\phi_{LO}}$ is the phase of the reference light signal 110.

At this time, if the SOP of the input light signal 100 precisely corresponds with the SOP of the reference light signal 110, light power detected by the photodetector 130 is expressed as the following equation 3:

Equation 3

$$P(t) = P_s + P_{LO} + 2\sqrt{P_s P_{LO}} \cos(\omega_{IF} t + \phi_s - \phi_{LO})$$

where, $P_s = KA_s^2$, $P_{LO} = KA_{LO}^2$, $\omega_{IF} = \omega_0 - \omega_{LO}$ and K is a constant.

However, if the SOP of the input light signal 100 does not precisely correspond with the SOP of the reference light signal 110, the light power of the equation 3 is expressed as the following equation 4:

Equation 4

$$P(t) = P_s + P_{LO} + 2\sqrt{P_s P_{LO}} \cos\alpha \cos(\omega_{IF} t + \phi_s - \phi_{LO}).$$

Equation 3 has a difference from equation 4 in that equation 4 further contains a term of $\cos\alpha$ compared with the equation 3. When it is defined that $\hat{e}_s$ and $\hat{e}_{LO}$ are respectively unit vectors of the input light signal 100 and the reference light signal 110, α indicates an angle between $\hat{e}_s$ and $\hat{e}_{LO}$.

FIG. 2 is a schematic view of an infinite polarization control way that approaches practical appliances at the present. In FIG. 2, like elements with those in FIG. 1 are designated by identical references.

Referring to FIG. 2, a transmission light signal 100 transmitted through an optical fiber 80 is mixed with a reference light signal 110 of a reference light source by a beam coupler 120a. In order to control polarization of the reference light signal 110, there is provided a first polarization controller 95 at a next stage of the reference light source 90. The mixed signal of the transmission light signal 100 and the reference light signal 110 passes through a beam splitter 120b and a part of the mixed signal is sent to a second polarization controller 160 to convert an SOP of the mixed signal to a desired SOP.

Remaining light signal split by the beam splitter 120b is detected by a photodetector 130. A central processing unit (CPU) 145 is operated depending on a detection result of the photodetector 130. In other words, the CPU 145 transmits a control signal to the first polarization controller 95 and changes the SOP of the reference light signal 110 depending on the SOP of the light signal such that the SOPs of the two light signals correspond. Also, the CPU 145 applies a voltage to the second polarization controller 160 using a result from a control algorithm of the CPU 145 and thereby changes the SOP of the transmission light signal 100 into a desired SOP.

In early methods for controlling polarization, there were used ways for changing birefringence of the optical fiber by applying a mechanical stimulus to the optical fiber. Thus, in order to change the birefringence mechanically, there was a motor or a PZT (Piezoelectric transducer) or the like. However, as such ways are applied, there

occur difficulties in stably controlling the polarization in that damage may be generated due to continuous mechanical stimuli or birefringence is sensitively varied with temperature.

Further, since the operation speed of the polarization controller depends on a response speed of the motor or the PZT, there is a problem in that it takes a few seconds or more. Other than the aforementioned birefringence changing ways, there are some methods for controlling polarization, for instance, electro-optic crystal way, Faraday rotator way, rotation wavelength plate way, etc. However, these ways also have a drawback in that their processes are complicated, mechanical operation is not constant, and operation voltage or operation current is very high.

Meanwhile, there are endeavors to realize the infinite polarization control using an optical integrated device employing lithium niobate ($LiNbO_3$). However, this method also has some problems such as high insertion loss, reflection, dc drift, etc.

Next, there is described a method for analyzing and computing state of polarization in order to define parameters used in the invention.

[Polarization analysis and computing method of state of polarization]

Upon controlling polarization using a polarizer, rotator, retarder, etc., there are used a Poincare sphere for the purpose of qualitative understanding and a matrix computing method such as Jones matrix or Muller matrix for the purpose of quantitative computation.

These methods simplify the polarization problem into a simple matrix computation and do not need consider complicated physical phenomena, so that error occurrence probability is much lowered.

Equator of the Poincare sphere means linearly polarized state and each pole means righthanded or lefthanded circularly polarized state. Remaining positions other than the equator and the poles in the Poincare sphere mean elliptically polarized state. Also, radius in the Poincare sphere means intensity of light. SOP on the Poincare sphere is expressed by Stokes vector $[S_0, S_1, S_2, S_3]^{-1}$ having parameters of S_0, S_1, S_2 and S_3.

FIG. 3 shows the Poincare sphere and Stokes parameters on the Poincare sphere.

In FIG. 3, when it is assumed that S_0 has a constant value, for instance, 1, S_0 can

be deleted. S_1 is a difference between horizontal polarization component of light and vertical polarization component of the light. It is meant that if the S_1 is greater than 0, the light is near the horizontal polarization while if the S_1 is less than 0, the light is near the vertical polarization. S_2 means which direction inclined the polarization of the light by 45 degrees. In other words, it is meant that if the S_1 is greater than 0, the polarization of the light is inclined by +45 degrees while if the S_1 is less than 0, the polarization of the light is inclined by –45 degrees. Also, it is meant that if the S_3 is greater than 0, the light is righthanded polarized while if the S_3 is less than 0, the light is lefthanded polarized. These Stokes parameters can be expressed in the following equation 5 using a spherical coordinate system (S0, 2χ, 2ψ):

Equation 5

$$S_1 = S_0 \cos 2\chi \cos 2\psi$$

$$S_2 = S_0 \cos 2\chi \sin 2\psi$$

$$S_3 = S_0 \sin 2\chi$$

where, χ(chi) is elliptical rate, and ψ(psi) is polarization angle. Accordingly, if the Stokes parameter values are known, elliptical rate and polarization angle can be obtained from the equation 5 and thereby SOPs of light can be expressed in points on the Poincare sphere.

FIG. 4 is a schematic diagram showing that the Stokes parameters can be expressed using the spherical coordinate system (S0, 2χ, 2ψ). On the contrary, if the elliptical rate and polarization angle are known, the Stokes parameter values of the light can be obtained.

When the SOP of the input light signal is expressed in Q_{sig}(S0, 2χ, 2ψ) on the Poincare sphere and the SOP of the reference light signal is expressed in Q_{LO}(S0', 2χ', 2ψ'), an angle, γ between these two components is expressed by the following equation 6.

Equation 6

$$2(1+\cos\gamma) = [(2\chi-2\chi')^2+(2\psi-2\psi')^2]^{1/2}$$

Thus, from the above equation 6, equation 4 and a relation of $\alpha=\gamma/2$(refer to chapter 3, "optic fiber network", Prentice Hall press co., 1993, P.E. Green Junior), a receiving power in the receiving part can be computed. As a representative method in which SOP of light is expressed in a matrix, there are Jones matrix and Muller matrix. Then, when the SOP of light is analyzed by using such a matrix together with the Stokes vector, 4×4 Muller matrix is used instead of 2×2 Jones matrix such that it corresponds with the Stokes parameter having four parameters.

When changing the SOP of light using a linear phase retarder, the changed SOP of light can be expressed using the Muller matrix as the following equation 7:

Equation 7

$$[S_0, S_1, S_2, S_3]^{-1}_{out} = M_\beta(\delta)[S_0, S_1, S_2, S_3]^{-1}_{initial}$$

where, $M_\beta(\delta)$ is Muller matrix, β is a twisted angle of the light phase retarder with respect to an optic axis, δ is a phase retardation value by the phase retarder, $[S_0, S_1, S_2, S_3]^{-1}_{initial}$ is a Stokes vector of the SOP of the input light signal, and $[S_0, S_1, S_2, S_3]^{-1}_{out}$ is a Stokes vector of the SOP of the output light signal, respectively.

Especially, in case that there is used liquid crystal as the phase retarder, $M_\beta(\delta)$ is expressed as the following equation 8:

Equation 8

$$M_\beta(\delta)=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C_2^2+S_2^2\cos\delta & S_2C_2(1-\cos\delta) & S_2\sin\delta \\ 0 & S_2C_2(1-\cos\delta) & S_2^2+C_2^2\cos\delta & -C_2\sin\delta \\ 0 & -S_2\sin\delta & C_2\sin\delta & \cos\delta \end{bmatrix}$$

where, $C_2=\cos 2\beta$, $S_2=\sin 2\beta$. Accordingly, when it is intended that the SOP of light, in particular, output light of reference light source is changed using a polarization controller having multiple light phase retarders, the SOP can be computed using the equation 7.

DISCLOSURE OF THE INVENTION

Accordingly, it is an object of the invention to provide a method and apparatus for detecting and controlling state of polarization in real time in which an algorithm for corresponding an SOP of a reference light signal with that of a transmission light signal is developed and thereby a computing time followed by a control of polarization is minimized.

To accomplish the above object and other features, there is provided an apparatus for detecting and controlling state of polarization in real time. The apparatus comprises: a reference light source for generating a reference light signal to grasp and control a state of polarization (SOP) of an input light signal; a first polarization controller for controlling polarization of the reference light signal; a coupler for coupling the polarization-controlled reference light signal with the input light signal in an SOP; a branching means for branching a part of the coupled light signal; a photodetecting means for detecting a beatingsignal out of the part signal branched from the branching means; an amplifying means for amplifying the beatingsignal detected by the photodetecting means; an A/D converter for digitalizing the amplified beatingsignal; a micro-control

unit and serial port for converting the digitalized beatingsignal into a signal capable of being processed in a computer, the computer executing a polarization control algorithm to grasp a control value of the first polarization controller, the control value corresponding to the SOP of the input light signal, in which the polarization control algorithm is executed only with respect to any quadrant of a circle obtained from a Poincare sphere by designating a direction through a movement of a reference point of the SOP; and a data acquisition board for applying a voltage corresponding to the control value of the first polarization controller obtained by the computer to the first polarization controller while applying a voltage to a second polarization controller positioned at an output terminal of the input light signal such that the SOP of the input light signal is changed into a desired SOP.

In the above apparatus, the reference light signal has a same wavelength as the input light signal, and preferably, the apparatus further comprises a temperature controller for variably controlling a temperature of the reference light source such that the reference light signal and the input light signal generate a predetermined beating signal.

Also, each of the first and second polarization controllers is preferably comprised of four liquid crystal light phase retarders arranged in one column.

Further, the reference light source is preferably a DFB-LD or a wavelength tunable laser.

According to another aspect of the invention, there is provided a method for detecting and controlling an SOP (State of polarization) in real time using the above apparatus. The method comprises the steps of: receiving a power information of the input light signal; detecting a position of a quadrant where the input light signal exists by controlling the first polarization controller, moving a reference point of the SOP and executing a direction designation mode for comparing a power value prior to the moving with a power value after the moving wherein the detecting is carried out on a circle in which, when the SOP of the input light signal is expressed in (S0, 2χ, 2ψ) on the Poincare sphere and the SOP of the reference light signal is expressed in (S0', $2\chi'$, $2\psi'$), an angle between the two SOPs is expressed by a following equation:

Equation

$$2(1+\cos\gamma) = [(2\chi-2\chi')^2+(2\psi-2\psi')^2]^{1/2},$$

the reference point having an elliptical rate and a polarization angle of zero; controlling the first polarization controller such that the elliptical rate and the polarization angle are varied, searching a point within the quadrant from the moved reference point, and detecting a point in which a power of the coupled signal of the input light signal and the reference light signal is in a maximum value; and detecting the SOP of the input light signal from the maximum power point of the coupled signal and controlling the second polarization controller to control the SOP of the input light signal into a desired SOP.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a system for detecting a variation in light power depending on states of polarization in input light signal and light signal of reference light source;

FIG. 2 is a schematic view of an infinite polarization control way;

FIG. 3 shows the Poincare sphere and Stokes parameters on the Poincare sphere;

FIG. 4 is a schematic diagram showing that the Stokes parameters can be expressed using the spherical coordinate system $(S0, 2\chi, 2\psi)$;

FIG. 5 is a schematic view of an apparatus for detecting and controlling state of polarization in real time in accordance with one preferred embodiment of the present invention;

FIG. 6 is a sectional view of one of four liquid crystal light phase retarders in a polarization controller used in the apparatus for detecting and controlling state of polarization in real time in accordance with one preferred embodiment of the present invention;

FIG. 7 is a schematic view for describing an operation when an external voltage is applied to the liquid crystal light phase retarder of FIG. 6;

FIG. 8 is a graph showing a phase retardation relation depending on an applied

voltage of the liquid crystal light phase retarder of FIG. 6;

FIG. 9 is a sectional view of a polarization controller used in the apparatus for detecting and controlling state of polarization in real time and having four liquid crystal light phase retarders in accordance with one preferred embodiment of the present invention;

FIG. 10 is a schematic view showing a light polarization control operation carried out on a Poincare sphere by the polarization controller of FIG. 9;

FIG. 11 is a flow chart showing an algorithm carried out in the polarization control apparatus of the present invention for the purpose of detecting and controlling state of polarization;

FIG. 12 is a schematic view for describing movement of a comparison reference point;

FIG. 13 is a schematic view for detecting which quadrant of four quadrants a polarization point of an input light signal is positioned at after the two-dimensional circle of FIG. 12 is divided into the four quadrants; and

FIG. 14 is an appearance view of a commercialized real-time automatic polarization controller in accordance with the present invention.

BEST MODEL FOR CARRING OUT OF THE INVENTION

Hereinafter, there is described a preferred embodiment in accordance with the present invention with reference to the accompanying drawings.

FIG. 5 is a schematic view of an apparatus for detecting and controlling state of polarization in real time in accordance with one preferred embodiment of the present invention. In the apparatus of FIG. 5, since an input signal 500 has an arbitrary wavelength, a reference light source 510 having the same wavelength as the input signal 500 is used. By controlling temperature of the reference light source 510 using a temperature controller 512 such that frequency of a beating signal becomes approximately 2GHz, the wavelength of the reference light source 510 is changed. Polarization of the reference light output from the reference light source 510 is converted through a first polarization controller 520 having four liquid crystal light

phase retarders. The reference light signal is mixed with the input light signal 500 through a coupler and the mixed light signal is detected by a 3 GHz pin photodiode 530.

The detected signal is amplified by an amplifier 540 because the signal is weak in intensity. A part of the amplified beating signal is input into a beating signal monitoring unit 542, and the remaining is input into a micro control unit (MCU) 560 via an A/D (Analog/digital) converter 550.

The MCU 560 transmits information of the received beating signal through a serial port 570 called UART (Universal Asynchronous Receiver and Transmitter) to a computer 575. The computer receives the information of the beating signal and carries out a polarization algorithm contained in the method of the invention. The MCU 560 obtains a liquid crystal bias voltage value corresponding to a state of polarization of the input light signal 500 from the computer 575, and applies the obtained liquid crystal bias voltage to the first polarization controller 520 through a DAQ (Data acquisition transmitter) 580 to thereby control the polarization of the reference light source 510. The input signal 500 and the reference light signal mixed through the coupler are feedback by the detection of the photodiode 530. The state of the polarization of the reference light source 510 is matched with the state of the polarization of the input light signal 500 and thereby the state of the input light signal is detected. A voltage is applied to a second polarization controller 590 to control the polarization of the input light signal 500 to a desired value. The second polarization controller 590 is arranged at a previous stage of an output signal 595 and includes four liquid crystal light phase retarders.

If the above apparatus is used in a field, a DFB-LD (Distributed feedback laser diode) having the same wavelength as the input light signal 500 is used as the reference light source 510. If the apparatus is used in a place for detecting and controlling the polarization of a specific input signal like laboratories, a wavelength tunable laser is used as the reference light source 510.

FIG. 6 is a sectional view of one of four liquid crystal light phase retarders in the polarization controller used in the apparatus of the present invention. In the liquid crystal light phase retarder of FIG. 6, nematic liquid crystal 600 is used as a liquid crystal layer, and is interposed between two glass substrates 620 coated with a

transparent electrode 610 such as indium tin oxide (ITO) in a thickness of 10-15 μm. A polymer layer 630 is disposed between the ITO electrode 610 and the glass substrate 620. Spacers 640 are also disposed at edge portions between the two glass substrates 620 in order to maintain a space between the two glass substrates 620.

FIG. 7 is a schematic view for describing an operation when an external voltage is applied to the liquid crystal light phase retarder of FIG. 6. Since elements of FIG. 7 are the same in the constitution as those of FIG. 6, reference numerals of FIG. 7 are intentionally deleted. In FIG. 7, (a) represents a case that an external voltage is not applied, (b) represents a case that a weak external voltage is applied, and (c) represents a case that a high external voltage is applied, respectively. If the applied voltage is greater than a threshold voltage that is necessary to rotate liquid crystal molecules and thereby the liquid crystal molecules are rotated by an angle of θ, an extraordinary refractivity n_e is changed into $n_e(\theta)$. At this time, a relationship between the rotating angle θ by the applied voltage and a variation in n_e by changing θ, i.e., $n_e(\theta)$ is expressed by the following equations 9 and 10:

Equation 9

$$\theta = \begin{cases} 0 \Lambda\ V \le V_{th} \\ \frac{\pi}{2} - \tan^{-1} \exp[-(V - V_{th)/V_0}] \Lambda\ V > V_{th} \end{cases}$$

Equation 10

$$n_e(\theta) = n_0[1 + (n_0^2 / n_e^2 - 1)\cos^2\theta]^{-1/2}$$

where, V is an applied voltage, V_{th} is threshold voltage of liquid crystal, V_0 is a constant, n_o is an ordinary refractivity, and n_e is an extraordinary refractivity.

A variation in birefringence of the liquid crystal, i.e., ne(θ)-no, is varied with the applied voltage and accordingly an optical phase retardation is expressed as the following equation 11:

Equation 11

$$\delta = (2\pi d / \lambda)(n_e(\theta) - n_o)$$

where, λ is a wavelength of light, and d is a thickness of the liquid crystal layer. The liquid crystal light phase retarder of the polarization controller used in the present embodiment employs a liquid crystal (product name: BL006) having refractive indexes of ne=1.8160 and no=1.5300, of which the threshold voltage is 2V and the thickness is 10 μm.

When the used light wavelength is 1,550 nm, a relation between the applied voltage to the liquid crystal light phase retarder and the phase retardation is shown in FIG. 8. From the relation of FIG. 8, and equations 7 and 8, a variation in the Stokes parameter depending on the variation in the voltage applied to the liquid crystal layer, i.e., a variation in the polarization is induced.

FIG. 9 is a sectional view of a polarization controller used in the apparatus for detecting and controlling state of polarization in real time and having four liquid crystal light phase retarders in accordance with one preferred embodiment of the present invention.

The conventional art for the infinite polarization control uses two or three birefringence changing units in order to generate an arbitrary SOP. In theory, at least three changing units make it possible to change an arbitrary SOP into a desired one. This can be understood with ease from the description in which an arbitrary point is moved to a desired position on the Poincare sphere. However, in most of birefringence changing units, there is a limit in their operation ranges. To this end, there exists a possibility that when moving the SOP to a specific point on the Poincare sphere, one of the three birefringence changing units reaches the operation range limit. To solve this problem, one birefringence changing unit is further provided and accordingly total four birefringence changing units are used. So, the polarization controller having four liquid crystal light phase retarders 800, 810, 820 and 830 are shown in FIG. 9. External voltages are respectively applied to the respective liquid crystal light phase retarders 800, 810, 820 and 830 in order to control a variation in the birefringence.

The polarization controller of FIG. 9 is described with the Poincare sphere. FIG. 10 is a schematic view showing a light polarization control operation carried out on the Poincare sphere by the polarization controller of FIG. 9. Horizontal and vertical linear polarization components are respectively indicated by H and V, +45 degrees and –45 degrees linear polarization components by P and Q, and lefthanded and righthanded circular polarization components by L and R as shown in FIG. 10. In FIG. 10, dotted line indicates a procedure in which an arbitrary SOP, i.e., a point "A" is changed into a desired SOP, i.e., a point "E" using four liquid crystal light phase retarders. Specifically, point A is moved to point B by the first phase retarder 800 with a rotational axis of H-V line on the sphere, point B is moved to point C by the second phase retarder 810 with a rotational axis of P-Q line, point C is moved to point D by the third phase retarder 810 with a rotational axis of the H-V line, and point D is moved to point E by the fourth phase retarder 830 with a rotational axis of the P-Q line. As shown in FIG. 9, the first to fourth phase retarders 800 – 830 are arranged with a phase difference by $\pi/4$ such that the SOP points of the pair of the first and third phase retarders 800 and 820 are moved with a central axis of the H-V line and the SOP points of the pair of the second and fourth phase retarders 810 and 830 are moved with a central axis of the P-Q line. In the present embodiment, a light phase retarder including a liquid crystal having the relationship shown in FIG. 8 is used. As shown in FIG. 8, a maximum range of the light phase retardation depending on a variation in the applied voltage is 3.5π or more. However, in order to guarantee a stable operation, the operation range is limited to $\pm\pi$, which satisfies a light phase retardation range that should be secured for controlling the polarization.

In other words, if the polarization controller shown in FIG. 9 is applied to a receiving part of an optical communications system, it is possible to change the polarization within a few milliseconds (ms) which is 1,000 times faster than a few seconds which is taken in driving a motor and varying PZT.

Generally, since the SOP of a transmission signal is changed after an elapse of a few hours to a few days in the optical cable buried in a length of a few hundred kilometers, the polarization controller has a sufficient polarization control speed within a

few seconds. However, if an intentional impact is applied to the optical cable in order to maintain and repair the optical cable, the polarization controller should have a polarization control speed in a unit of milliseconds. In the above case, the polarization controller having the liquid light phase retarders in accordance with the present invention can satisfy such a requirement.

Also, if liquid crystal is used as a birefringence changing unit for light phase retardation, its operation range is wider than other units and there is a margin in changing the SOP, so that the optical communications receiving system is in a stable state.

In an operation of the apparatus for detecting and controlling the polarization state, in which the aforementioned polarization controller is included, the inventor invented a method for minimizing a computing time according to a polarization control by developing an algorithm for corresponding the SOP of the reference light signal with the SOP of the input light signal based on the polarization control principles. Power value obtained in equation 4 is the one and only information capable of confirming correspondence in the SOP at the receiving terminal. Accordingly, this polarization control algorithm targets a faster searching of a received SOP using the power value of a received signal.

Polarization Control Algorithm

Polarization control algorithm has the following constitution.

Returning to FIG. 4, polarization of an arbitrary light is expressed by elliptical rate χ and polarization angle ψ. If polarization in a point where elliptical rate χ and polarization angle ψ are zero is defined as a reference point, an arbitrary point on the Poincare sphere, i.e., an arbitrary polarization, can be expressed in an angle between the two points, γ. Accordingly, all points on the Poincare sphere are expressed in different γ values with a point where elliptical rate χ and polarization angle ψ are zero as a reference point. At this time, since the elliptical rate χ of the reference light signal and the polarization angle ψ become zero, the equation 6 represents a two-dimensional circle having a radius of γ, and the SOP of the input light signal represents one point on the

two-dimensional circle. Based on the aforementioned comcepts, if respective points on the sphere are set with an interval of one degree, the SOP of the input light signal represents one point on the two-dimensional circle. Accordingly, it is sufficient to retrieve only 360 points on the two-dimensional circle without retrieving all points of 180×360 on the sphere. At this time, in order to retrieve the SOP of the input light signal within the shortest time, a new reference point is set through a dithering operation and then the SOP of the input light signal is searched. When the SOP of the input light signal is detected, it is possible to control the polarization of the input light signal based on the detected SOP.

FIG. 11 shows an algorithm for automatically detecting and controlling the polarization sate in real time. Referring to FIG. 11, power information of the input light signal is first received. (S1110) After that, there are detected points having the same power value on the sphere in the center of a point where the elliptical rate χ and the polarization angle ψ are both zero, i.e., 360 number of points (number of points arranged with an interval of one degree on the two-dimensional circumference) on a circle having the same radius as shown in FIG. 12. At this time, a precondition is that power values of the input light signal and the reference light signal are previously known to.

Thereafter, a dithering step is carried out prior to a searching step of the SOP of the input light signal. In other words, a two dimensional circle is divided into four pieces, under a circumstance in which it is not known that which of the circle the point of the SOP of the input light signal is positioned at, a comparing reference point A (where the elliptical rate χ and the polarization angle ψ are both zero) of FIG. 12 is moved to a right side of the reference point along the HV axis, a power value (P_{new}) is measured, the measured power value is compared with a power value (P_{old}) of a signal of prior to moving the reference point, the comparing reference point is upwardly moved along the PQ axis, and a power value (P_{new}) is measured. (S1120)

By comparing the power value (P_{new}) of after the reference point is moved with the power value (P_{old}) of before the reference point is moved, it is known whether the point of the SOP of the input light signal exists on a quadrant. Thereby, an endeavor for searching the whole circle decreases to 1/4, which means an improvement in the

operation speed of the polarization control system. At this time, a relationship between the power value and the polarization point.

First, the reference point is moved to a right side of the reference point along the HV axis and then power values are compared.

1) In a case of $P_{new} > P_{old}$, the SOP of the input light signal exists at a quadrant I, or a quadrant IV.

1-1) a case that the reference point is moved onto the reference point along the PQ axis and power values are compared.

1-1-1) In a case of $P_{new} > P_{old}$, the SOP of the input light signal exists at the quadrant I.

1-1-2) In a case of $P_{new} < P_{old}$, the SOP of the input light signal exists at the quadrant IV.

2) In a case of $P_{new} < P_{old}$, the SOP of the input light signal exists at a quadrant II, or a quadrant III.

2-1) a case that the reference point is moved onto the reference point along the PQ axis and power values are compared.

2-1-1) In a case of $P_{new} > P_{old}$, the SOP of the input light signal exists at the quadrant II.

2-1-2) In a case of $P_{new} < P_{old}$, the SOP of the input light signal exists at the quadrant III.

There is described a work for searching a precise point on a quadrant where the polarization point of the input light signal exists after the reference point is set by the dithering operation using examples of points A, B, and C of FIG. 12. In these examples, as a result of the dithering operation, an object sphere for the searching work of the polarization point is positioned at the quadrant II on plane. In this case, point B is set as a new reference point and light powers are compared while approaching point C from the reference point, i.e., changing χ and ψ. (S1140) If a maximum light power is obtained in this step, it is meant by that the point is a precise polarization point of a received light. Thus, by applying a peak-search algorithm within the shortest time under a circumstance having the one and only information of light power, the polarization

components of the input light signal, i.e., elliptical rate and polarization angle are obtained. (S1160) After the SOP of the input light signal is detected by the aforementioned way, it is possible to control the polarization of the input light signal using the liquid crystal polarization controller of the receiving terminal. (S1170)

The aforementioned algorithm is characterized in that the polarization controller is directly not operated except for the dithering operation during a procedure in which the polarization is controlled such that the SOP of the reference light signal corresponds with the SOP of the input light signal. Unlike the above, the conventional feedback algorithm repeatedly operates the polarization controller through feedback until a precise SOP value is obtained.

Operation times being small is meant by that the operation speed of the whole control system is fast as much as that. Accordingly, it is known that the method of the present invention is considerably improved compared with the conventional polarization control method in aspects of superior property of substance (liquid crystal) used as the light phase retarder and fast control algorithm.

FIG. 14 is an appearance view of a commercialized real-time automatic polarization controller in accordance with the present invention. Inside the commercialized product, there is disposed the personal computer (PC) shown in FIG, in which a program executed in window (Trademark) is installed to provide a user friendly interface environment. Also, the computer is a core for the real-time polarization controller and it makes it possible to control all hard wares at one place. The picture of FIG. 14 shows a procedure that a control algorithm of the real-time polarization controller is applied on the Poincare sphere in the window environment. At the right upper portion of the picture, there are a receiving part for receiving power information of the input light signal and the reference light signal, a button for executing the control algorithm. At the right lower portion, there is shown a voltage value to be applied to the liquid crystal light phase retarder of the polarization controller. The control algorithm is executed on the Poincaré sphere shown in the picture, to automatically show in real time a trace that the SOP of the reference light signal tracks a random SOP of the input light signal, and a trace that after the SOP of a transmission signal is detected, the SOP of the

transmission signal is moved to a desired SOP. Below the Poincare sphere, there is shown a variation in power depending on a variation in the SOPs of the transmission signal and the reference light signal. In case that a 450 MHz Pentium III (Trademark) is used in the personal computer, the operation speed of the control algorithm is nothing but a few micro seconds.

INDUSTRIAL APPLICABILITY

According to the present invention, an algorithm for corresponding an SOP of a reference light signal with that of a transmission light signal is developed and thereby a computing time followed by a control of polarization is minimized, so that the SOP can be detected and controlled within the shortest time.

What is claimed is:

1. An apparatus for detecting and controlling state of polarization in real time, the apparatus comprising:

a reference light source for generating a reference light signal to grasp and control a state of polarization (SOP) of an input light signal;

a first polarization controller for controlling polarization of the reference light signal;

a coupler for coupling the polarization-controlled reference light signal with the input light signal in an SOP;

a branching means for branching a part of the coupled light signal;

a photodetecting means for detecting a beatingsignal out of the part signal branched from the branching means;

an amplifying means for amplifying the beatingsignal detected by the photodetecting means;

an A/D converter for digitalizing the amplified beatingsignal;

a micro-control unit and serial port for converting the digitalized beatingsignal into a signal capable of being processed in a computer, the computer executing a polarization control algorithm to grasp a control value of the first polarization controller, the control value corresponding to the SOP of the input light signal, in which the polarization control algorithm is executed only with respect to any quadrant of a circle obtained from a Poincare sphere by designating a direction through a movement of a reference point of the SOP; and

a data acquisition board for applying a voltage corresponding to the control value of the first polarization controller obtained by the computer to the first polarization controller while applying a voltage to a second polarization controller positioned at an output terminal of the input light signal such that the SOP of the input light signal is changed into a desired SOP.

2. The apparatus of claim 1, wherein the reference light signal has a same wavelength as the input light signal, the apparatus further comprises a temperature

controller for variably controlling a temperature of the reference light source such that the reference light signal and the input light signal generate a predetermined beating signal.

3. The apparatus of claim 1, wherein each of the first and second polarization controllers is comprised of four liquid crystal light phase retarders arranged in one column.

4. The apparatus of claim 1, wherein the reference light source is a DFB-LD or a wavelength tunable laser.

5. A method for detecting and controlling an SOP (State of polarization) in real time using the apparatus of claim 1, the method comprising the steps of:

receiving a power information of the input light signal;

detecting a position of a quadrant where the input light signal exists by controlling the first polarization controller, moving a reference point of the SOP and executing a direction setting mode for comparing a power value prior to the moving with a power value after the moving wherein the detecting is carried out on a circle in which, when the SOP of the input light signal is expressed in ($S0$, 2χ, 2ψ) on the Poincare sphere and the SOP of the reference light signal is expressed in ($S0'$, $2\chi'$, $2\psi'$), an angle between the two SOPs is expressed by a following equation:

Equation

$$2(1+\cos\gamma) = [(2\chi-2\chi')^2+(2\psi-2\psi')^2]^{1/2},$$

the reference point having an elliptical rate and a polarization angle of zero;

controlling the first polarization controller such that the elliptical rate and the polarization angle are varied, searching a point within the quadrant from the moved reference point, and detecting a point in which a power of the coupled signal of the input light signal and the reference light signal is in a maximum value; and

detecting the SOP of the input light signal from the maximum power point of the coupled signal and controlling the second polarization controller to control the SOP of the input light signal into a desired SOP.

FIG. 1
(Prior Art)

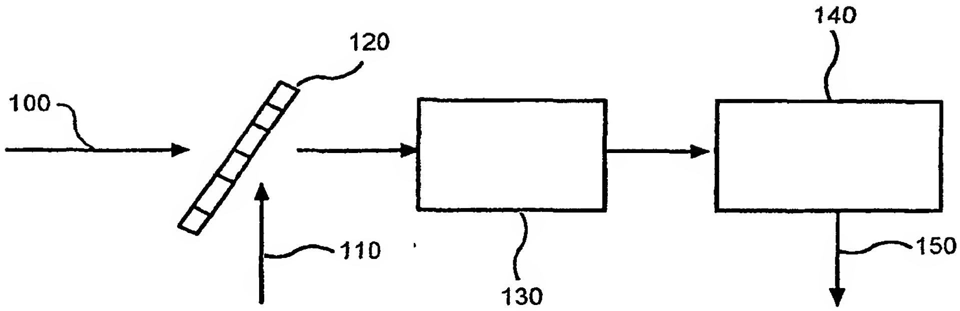


FIG. 2
(Prior Art)

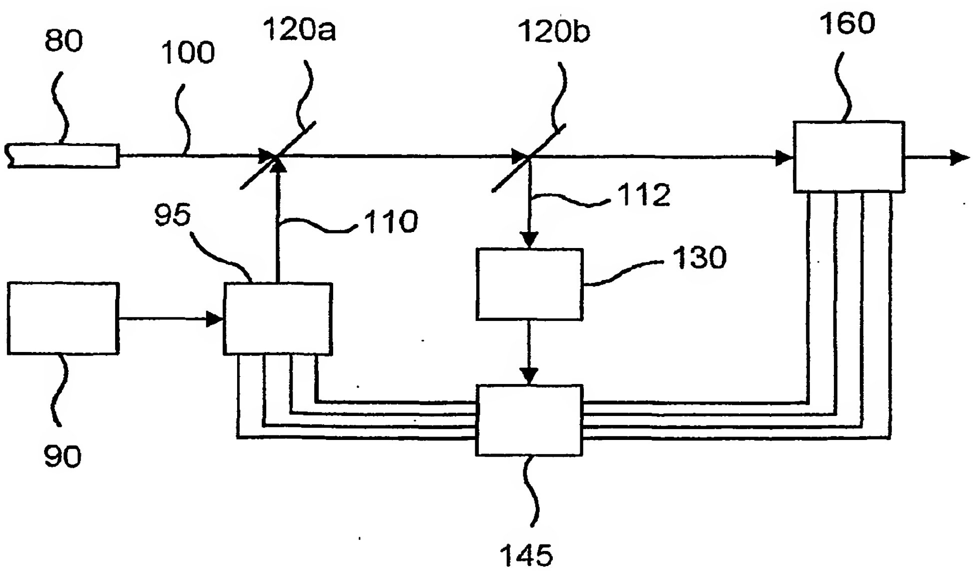


FIG. 3
(Prior Art)

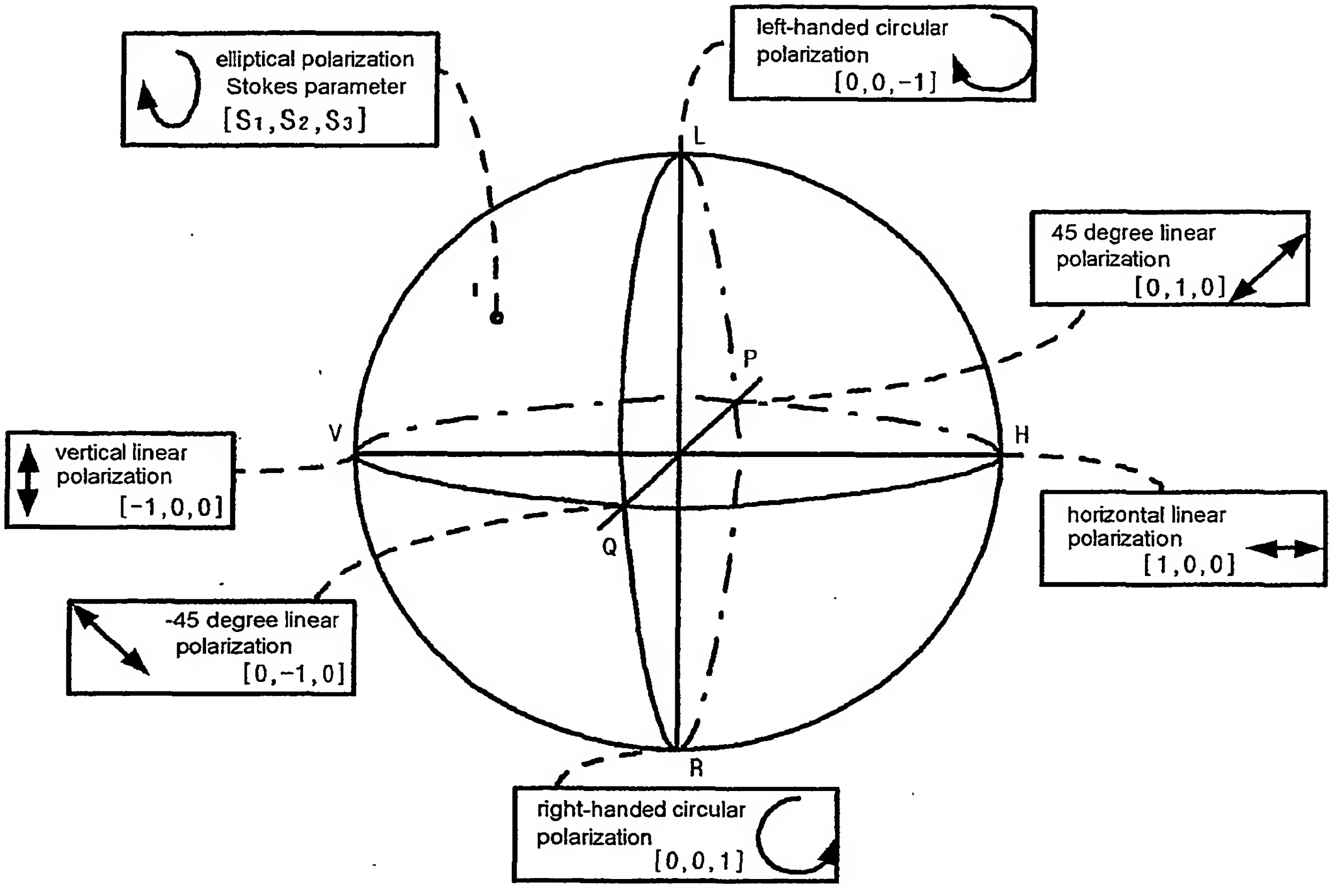


FIG. 4
(Prior Art)

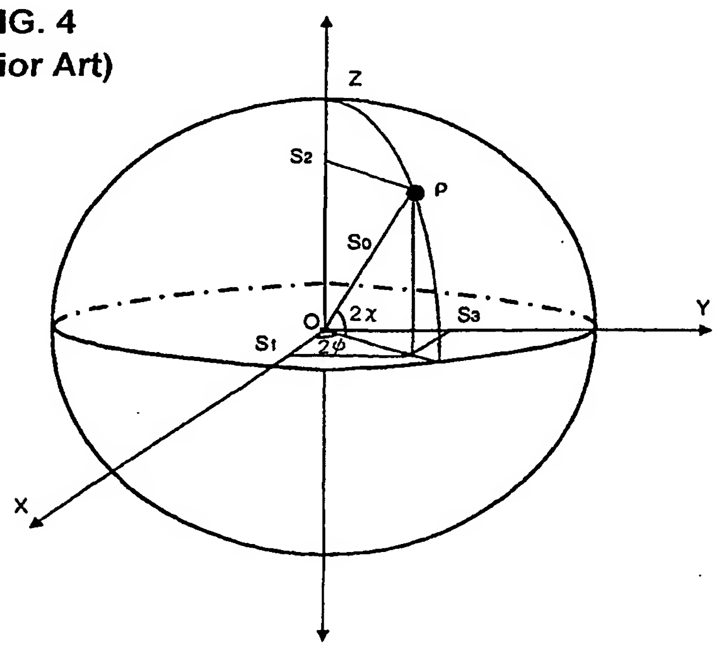


FIG. 5

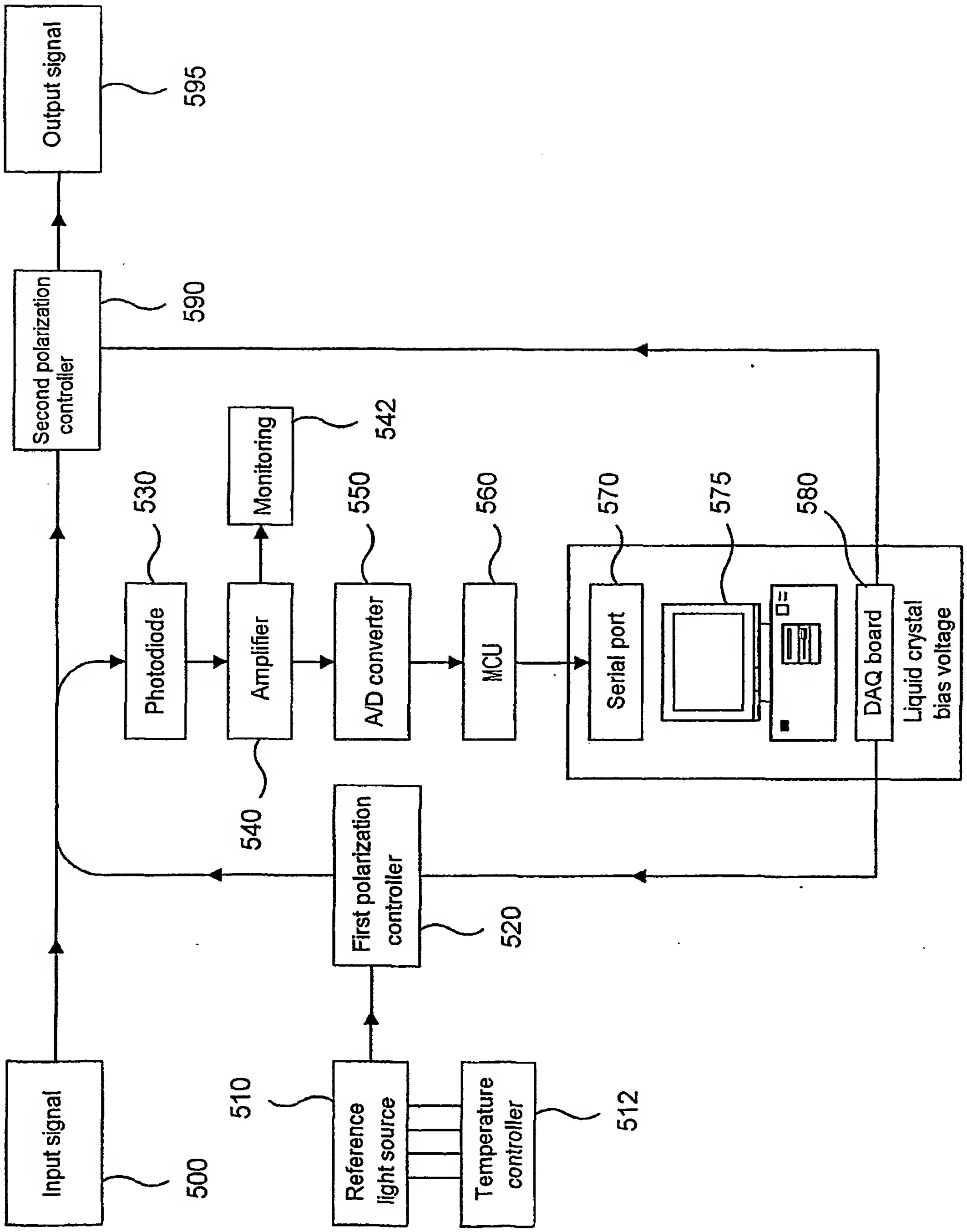

Input signal
500
Reference light source
510
Temperature controller
512
First polarization controller
520
Photodiode
530
Amplifier
540
Monitoring
542
A/D converter
550
MCU
560
Serial port
570
575
DAQ board
580
Liquid crystal bias voltage
Second polarization controller
590
Output signal
595

FIG. 6

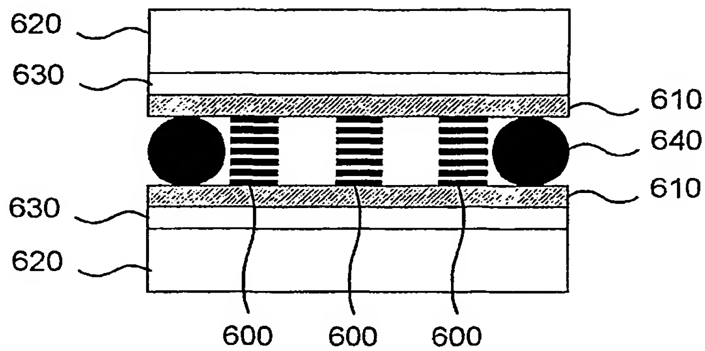


FIG. 7

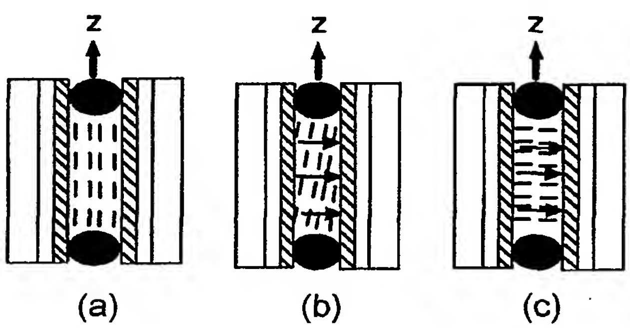


FIG. 8

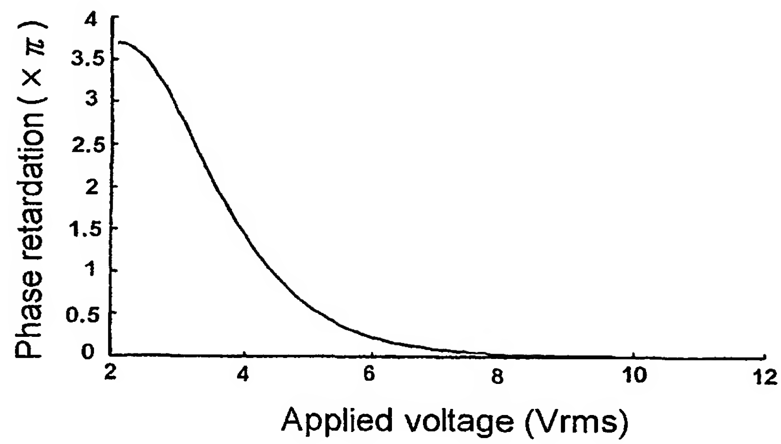

Phase retardation (× π)
4
3.5
3
2.5
2
1.5
1
0.5
0
2
4
6
8
10
12
Applied voltage (Vrms)

FIG. 9

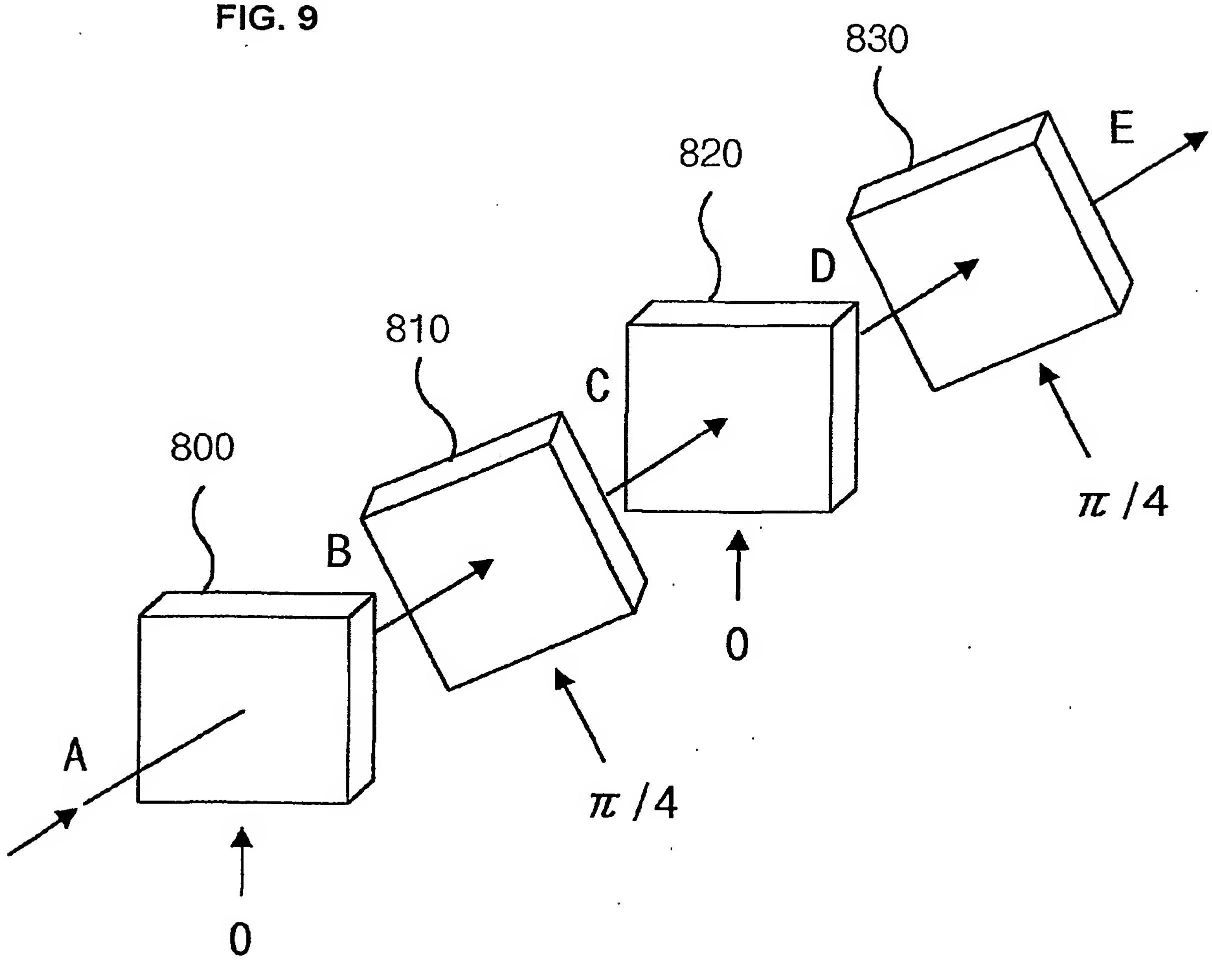

830
E
820
D
810
C
800
B
A
π /4
0
π /4
0

FIG. 10

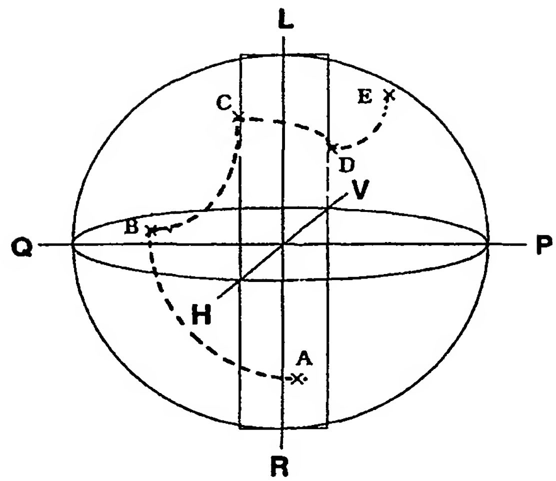

L
C
E
D
V
Q
B
P
H
A
R

FIG. 11

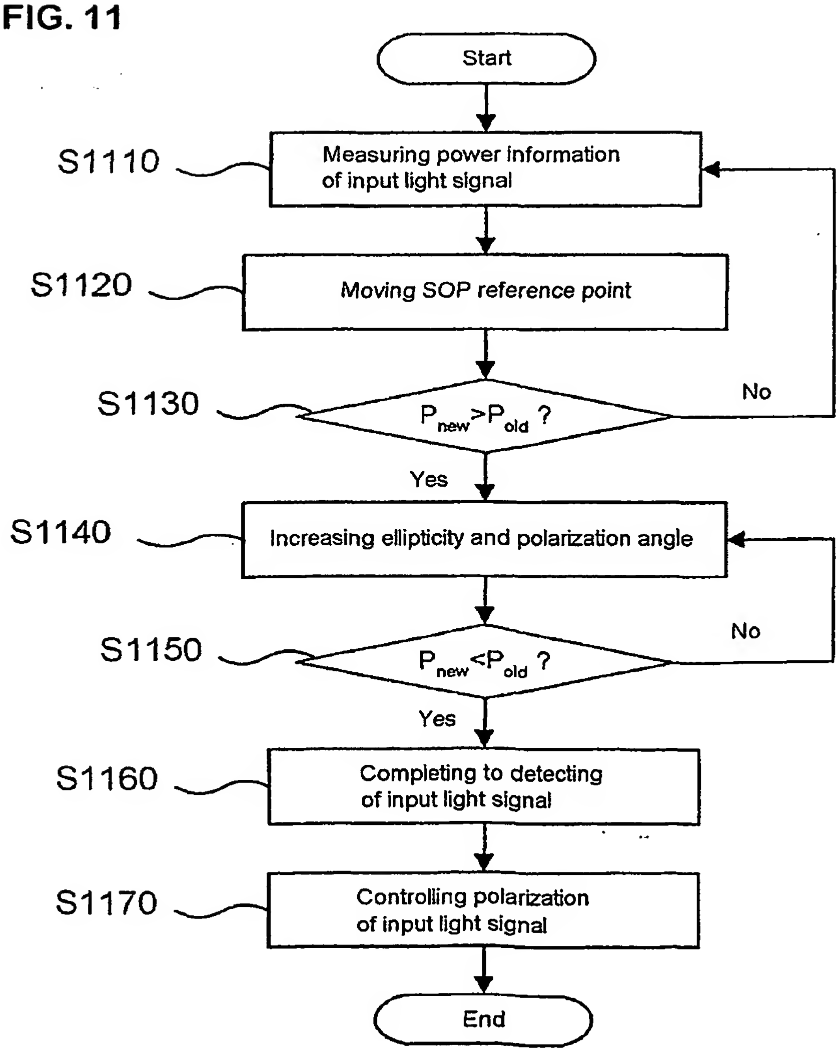

Start
S1110
Measuring power information of input light signal
S1120
Moving SOP reference point
S1130
$P_{new} > P_{old}$?
No
Yes
S1140
Increasing ellipticity and polarization angle
S1150
$P_{new} < P_{old}$?
No
Yes
S1160
Completing to detecting of input light signal
S1170
Controlling polarization of input light signal
End

FIG. 12

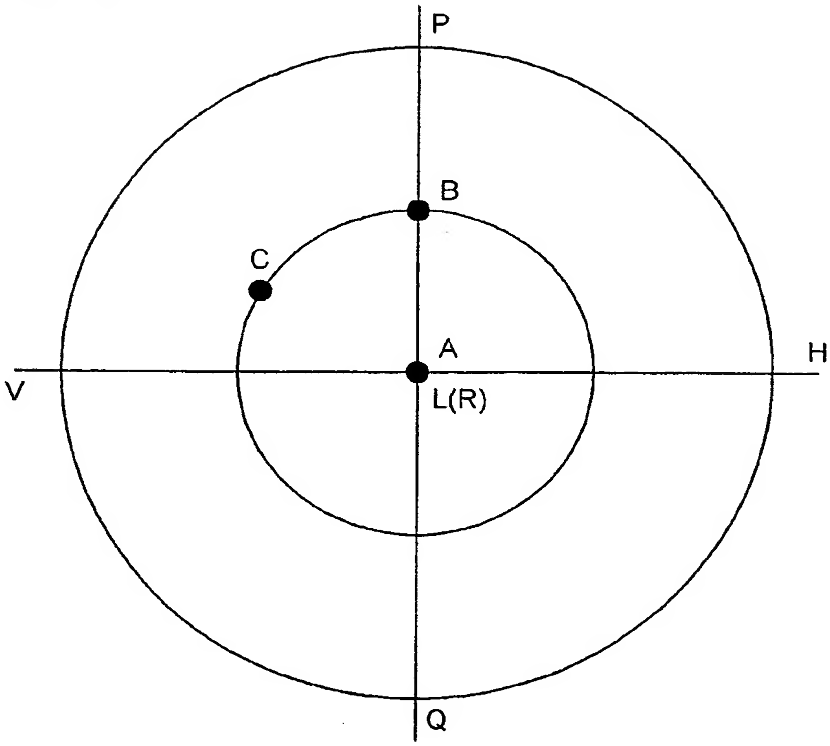


FIG. 13

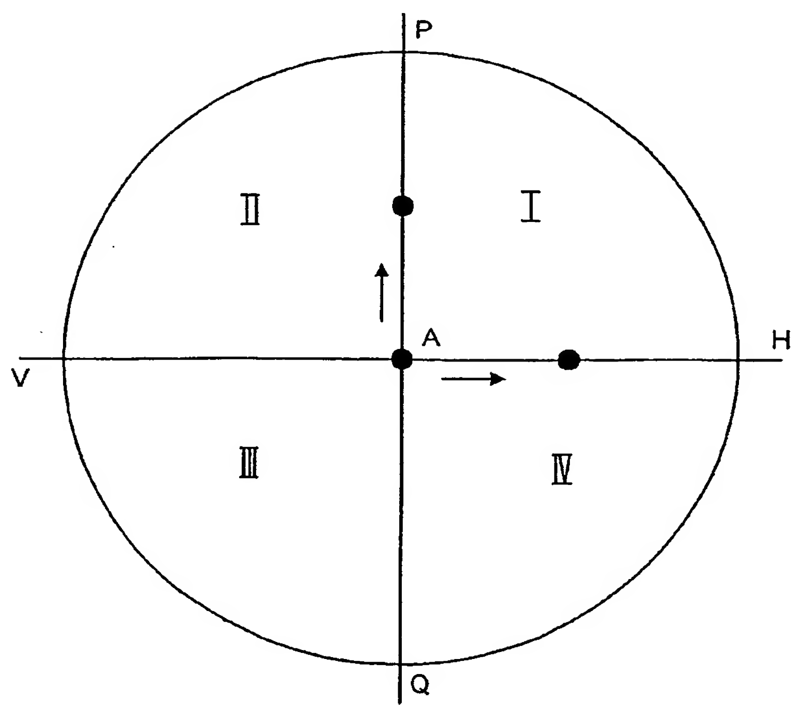
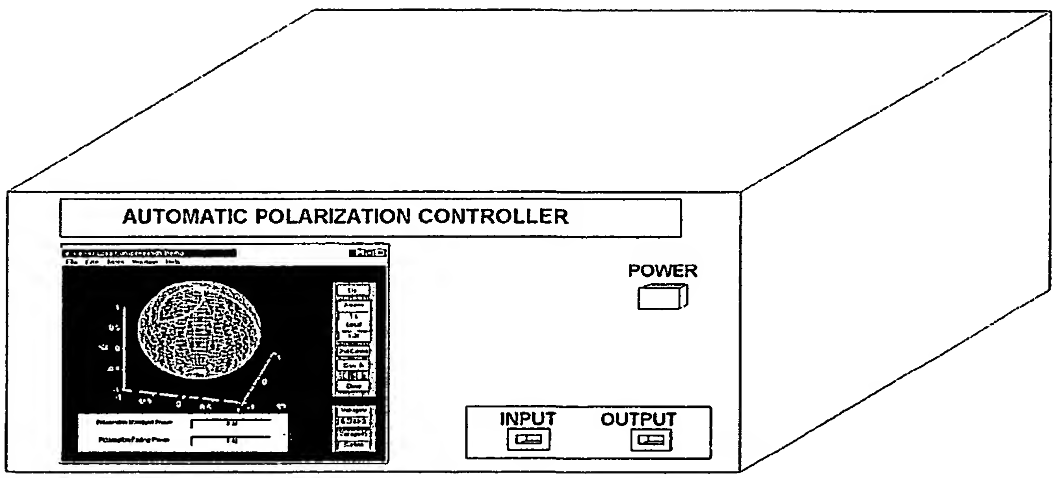


FIG. 14



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR00/00890

A. CLASSIFICATION OF SUBJECT MATTER

IPC7 G02B 26/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimun documentation searched (classification system followed by classification symbols)
IPC7 G02B, G02F, H04B

Documentation searched other than minimun documentation to the extent that such documents are included in the fileds searched
Korean Patents and applications for inventions since 1975
Korean Utility models and applications for Utility models since 1975

Electronic data base consulted during the intertnational search (name of data base and, where practicable, search trerms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 263612 A (British Telecommunications Public Limited Company) 18 Sep. 1987 See whole documents	1-3
A	EP 630122 A (Fred Ludwic Heismann, Robert L. Rosenberg) 07 June 1994 See whole documents	1
A	GB 2184253 A (STC PLC.) 17 June 1987 See whole documents	1
A	JP 10-197840 A (Koshin Kogaku)) 31 July 1998 See whole documents	1-3

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevence
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevence; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevence; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 APRIL 2001 (25.04.2001)	27 APRIL 2001 (27.04.2001)

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office Government Complex-Taejon, Dunsan-dong, So-ku, Taejon Metropolitan City 302-701, Republic of Korea	SHIN, Un Cheol
Facsimile No. 82-42-472-7140	Telephone No. 82-42-481-5585

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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